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Speckled dace (Rhinichtys asculus) are more tolerant of air-supersaturated water than adult or juvenile cutthroat trout (Salmo clarki). Speckled dace were tested in concentrations from 110 to 142% saturation and had a 96-hour median lethal concentration (LC50) of 140%, a 7-day LC50 of 137% and 2-week LC50's of 129 and 131% saturation. The estimated mean threshold concentration, based on time to 50% death (TM50), was 123% saturation. The speckled dace also exhibited consistent external signs of gas bubble disease. Cutthroat trout were tested from 111 to 130% saturation and had 96-hour LC50's of119 and 120% (adults) and 119 and 119% (juveniles) saturation. Estimated mean threshold concentrations (from TM50 values) were 117% (adults) and 114% (juveniles) saturation. Signs of gas bubble disease exhibited by the cutthroat trout were similar to those seen with other salmonids examined in earlier studies.

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Comparative Responses of Speckled Dace and Cutthroat Trout to Air-Supersaturated Water

ALAN V. NEBEKER, A. KENT HAUCK,[1]
FAYE D. BAKER, AND STEPHEN L. WEITZ

United States Environmental Protection Agency, Corvallis Environmental Research Laboratory
Western Fish Toxicology Station, 1350 Southeast Goodnight Avenue
Corvallis, Oregon 97330

Abstract

Speckled dace (*Rhinichthys osculus*) are more tolerant of air-supersaturated water than adult or juvenile cutthroat trout (*Salmo clarki*). Speckled dace were tested in concentrations from 110 to 142% saturation and had a 96-hour median lethal concentration (LC50) of 140%, a 7-day LC50 of 137%, and 2-week LC50's of 129 and 131% saturation. The estimated mean threshold concentration, based on time to 50% death (TM50), was 123% saturation. The speckled dace also exhibited consistent external signs of gas bubble disease. Cutthroat trout were tested from 111 to 130% saturation and had 96-hour LC50's of 119 and 120% (adults) and 119 and 119% (juveniles) saturation. Estimated mean threshold concentrations (from TM50 values) were 117% (adults) and 114% (juveniles) saturation. Signs of gas bubble disease exhibited by the cutthroat trout were similar to those seen with other salmonids examined in earlier studies.

In order to predict the impact of a harmful chemical or other factor on an aquatic environment, data are needed on the individual biotic components of the system to determine what may be harmfully affected or eliminated if the stress is not abated. In the case of air supersaturation in the Columbia River system, supersaturation will continue to occur during years of high water runoff, even with the abatement procedures now part of the complex management plans of the river system. A large data base is now available on dominant economic fish species, anadromous steelhead (*Salmo gairdneri*) and salmon (*Oncorhynchus* spp.) (Bouck et al. 1976), but very little information is available for other important components of the ecosystem. The responses to environmental stress of fish species native to the Columbia River such as speckled dace (*Rhinichthys osculus*), a representative of a large and diverse group of fishes not previously tested, also need to be observed. Little is known about the susceptibility of speckled dace to toxicants and no data are available dealing with supersaturation. Likewise, relatively little information is available for the cutthroat trout (*Salmo clarki*). Field data on the survival of cutthroat trout in air-supersaturated water were obtained by May and Huston (1975) from the Kootenai River below Libby Dam in Montana. Excess spilling through the dam's sluiceways has supersaturated the water with air and killed many fish below the dam. The cutthroat trout appeared to be one of the more sensitive species affected.

This field information, along with the information from Blahm et al. (1976) prompted us to use the cutthroat trout along with the speckled dace for some detailed comparative studies. In addition, Fickeisen and Montgomery (1978) present data on the effects of water depth on survival of cutthroat trout with water at 132% saturation.

Methods

Unchlorinated well water with the following characteristics was used for all testing: hardness (as $CaCO_3$), 23 mg/liter; alkalinity (as $CaCO_3$), 22 mg/liter; pH, 7.1. Dissolved oxygen was maintained near saturation or higher at all times. Chemical analyses were conducted according to the American Public Health Association et al. (1971). Water was supersaturated by injecting compressed air into the water supply under pressure (Bouck et al. 1976; Nebeker et al. 1976) and then releasing the water to the test facility under normal atmospheric pressure. The percent saturation was controlled by

[1] Present address: Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, Alaska 99502.

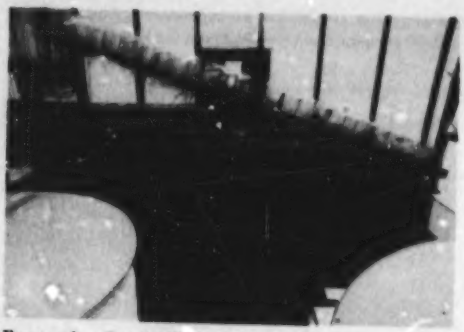

FIGURE 1.—*Test facility for speckled dace. Supersaturated water is delivered to the top of the partitioned ladderlike box where it cascades down over the partitions, which serially strip the water of excess gas, making it possible to draw off any concentration desired and to deliver it to aquaria below.*

the amount of air injected into the water. Saturation levels were measured with the Weiss saturometer, the Van Slyke gas analyzer, gas chromatography, and Winkler dissolved-oxygen determinations. The formula 100 (BP + ΔP − VP)/BP = percent saturation, where BP = atmospheric pressure, ΔP = Weiss saturometer reading, and VP = water vapor pressure, was used to calculate total percent saturation values. After being supersaturated, water for the speckled dace tests was delivered to the top of a partitioned ladderlike box (Fig. 1), from where it cascaded down and over partitions. The partitions serially stripped the water of excess gas, making it possible to draw off any concentration of supersaturated water desired. Water of several supersaturation concentrations was then delivered to 100-liter aquaria. Water for the cutthroat trout tests was supersaturated and delivered directly to the test tanks by a separate air injection system for each tank.

Juvenile speckled dace were collected with dip nets from the south fork of the Alsea River, Benton County, Oregon, and transported to the laboratory for acclimation. They were fed Oregon Moist Pellets (OMP) daily and frozen brine shrimp (*Artemia* sp.) once a week during holding and testing. The speckled dace adapted immediately to laboratory conditions and no mortality or disease problems occurred during holding. Mean size of the fish during testing was 3.5 cm fork length. Adult and juvenile cutthroat trout used for testing were hatched and reared from eggs obtained from the North Fork Hatchery (Alsea River, Benton County, Oregon) of the Oregon Department of Fish and Wildlife. Fish were fed OMP during testing. Mean adult fork length and weight during testing were 23.5 cm and 121.5 g. Mean juvenile fork length and weight were 6.7 cm and 3.5 g.

Three tests with speckled dace were conducted in 100-liter aquaria (21, 35, and 32 days each). Test supersaturation concentrations ranged from 143% to 100% total gas saturation (Table 1). Test temperatures were 10 C (Tests 1 and 2) and 12 C (Test 3), and water depth was 25 cm. Five duplicate concentrations and controls were used for each test. Ten fish were placed in each aquarium in Tests 1 and 2; six or seven fish (12–14/concentration) were placed in each aquarium in Test 3. Fish were randomly placed in the aquaria and natural photoperiod with subdued light intensities was used during testing.

Three separate tests with cutthroat trout were conducted (7, 21, and 21 days each) at 12 C, with natural photoperiod and air-supersaturated water at concentrations of 130%, 126%, 124%, 121%, 118%, 115%, 112%, and 100% total air saturation (Table 1). Testing of duplicate groups of adults and juveniles in the same concentrations of air-supersaturated water (60 cm depth) was conducted in four separate net cages placed in 6,000-liter fiberglass tanks. Ten adults and twenty juveniles were tested, each group with duplicates in separate cages giving a total of 60 fish tested at each level of saturation of air-supersaturated and control water. Data were analyzed and presented as concentrations causing 50% mortality (LC50), times to 50% and 20% death (TM50 and TM20), and threshold values (concentrations at which deaths begin to occur). The LC50 values with their confidence values were obtained by the logistic regression methods of Finney (1971). Threshold values were estimated by methods summarized by Sprague (1969).

Results

Speckled dace were less sensitive to air-supersaturated water than cutthroat trout and exhibited different sublethal signs of gas bubble disease. However, they were more sensitive than a 96-hour test would indicate (Tables 1, 2). It took a week or more before they began to exhibit problems at supersaturation concen-

TABLE 1.—*Mean time to 50% and 20% death for juvenile speckled dace at 10–12 C in air-supersaturated water 25 cm deep; and adult and juvenile cutthroat trout at 12 C in test water 60 cm deep. Dash (—) indicates less than 50% or 20% mortality occurred.*

Fish	Test	Temperature (C)	Fish per concen-tration	Percent saturation Mean ± SD	Mean time to 50% death (hours)	Mean time to 20% death (hours)
Speckled dace	Juveniles	10	10	130 ± 2	265	140
				130 ± 2	325	210
				125 ± 2	380	175
				125 ± 2	—	290
				120 ± 1	—	420
				120 ± 1	—	—
				115 ± 1	—	—
	Juveniles	10	10	130 ± 2	560	365
				128 ± 1	340	135
				124 ± 1	485	260
				123 ± 2	—	405
				120 ± 2	—	720
				118 ± 1	—	550
				115 ± 1	—	—
	Juveniles	12	6–7	143 ± 3	62	34
				142 ± 3	25	15
				138 ± 2	116	46
				137 ± 3	117	53
				131 ± 2	255	105
				131 ± 2	242	114
				124 ± 2	580	255
				124 ± 2	—	—
Cutthroat trout	Adults	12	20	130 ± 1	11	8
				126 ± 1	20	16
				124 ± 1	29	20
				120 ± 1	97	64
	Adults	12	20	121 ± 1	42	34
				118 ± 1	265	142
				114 ± 1	—	—
				112 ± 1	—	—
	Adults	12	20	120 ± 1	67	44
				118 ± 1	172	151
				115 ± 1	—	—
				112 ± 1	—	—
	Juveniles	12	40	121 ± 1	97	50
				118 ± 1	170	109
				114 ± 1	349	246
				112 ± 1	—	—
	Juveniles	12	40	120 ± 1	54	20
				118 ± 1	119	79
				114 ± 1	315	185
				112 ± 1	—	—

trations near 130%, although at 140% deaths began occurring within 24 hours. All of the speckled dace at 130% had moderate to severe exophthalmia (pop eye) with periorbital accumulation of gas and hemorrhaging. A few fish had bubbles in fin rays, a common sign of gas bubble disease in salmonids. Also, those few dace usually had bubbles only in the ventral half of the caudal fin. The fish consistently exhibited emphysemas (bubbles) in the mouth, on the lower jaw and branchiostegal area, and in the gill cavity. Death could have been caused by asphyxia resulting from blockage of water flow over the gills. Also, due to the excessive gas accumulation in the head tissues the fish were buoyed to the water surface and had difficulty staying near the tank bottom. Feeding was also difficult or impossible due to emphysemas in the oral and gill tissues. Hemorrhaging was observed in the kidney, liver, and at the base of

TABLE 2.—*Summary of effects of air-supersaturated water on juvenile speckled dace and adult and juvenile cutthroat trout. Dashes (—) indicate insufficient deaths.*

Fish	Test	96-hour LC50[a] (% saturation) (95% confidence interval)	7-day LC50 (% saturation) (95% confidence interval)	2-week LC50 (% saturation) (95% confidence interval)	Mean lethal threshold concentration[b] (% saturation)	
					50% death	20% death
Speckled dace	Juveniles	—	—	129 (127–134)		
	Juveniles	—	—	—	125	119
	Juveniles	140 (137–146)	137 (135–141)	131 (128–134)		
Cutthroat trout	Adults	119 (118–120)	118 (118–121)	118 (118–122)	117 (adults)	116 (adults)
	Adults	120 (119–121)	118 (118–119)	118 (117–119)		
	Juveniles	119 (119–120)	118 (118–119)	115 (114–115)	114 (juveniles)	113 (juveniles)
	Juveniles	119 (118–119)	116 (115–118)	115 (114–115)		

[a] LC50 = Calculated lethal concentration at which 50% died in 96 hours (or 7 days or 2 weeks).
[b] Lethal threshold concentration = concentration where significant mortality begins to occur. Estimated from time to 50% or 20% death at each concentration.

the paired fins; petechial hemorrhaging occurred on the peduncle and near the base of the fins. Subcutaneous bubbles, often measuring 1 cm in diameter, were sometimes observed on the head or side of the body.

The 96-hour LC50 for speckled dace was 140% saturation, much higher than that of cutthroat trout. The 7-day LC50 of 137% was similar, as one would expect, to the 96-hour LC50 and again, much higher than that of cutthroat (Table 2). The 2-week LC50's were 129 and 131%, lower than the 7-day LC50 but not as low as the mean estimated threshold concentration, which was near 123% when calculated from the time to 50% mortality, and 119% when calculated from the time to 20% mortality.

Juvenile cutthroat trout were more sensitive to supersaturated water than adults (Tables 1, 2) with 96-hour LC50's of 119% (juveniles) and 120% (adults) saturation. Adults died rapidly at 150% saturation. Juveniles and adults died in about the same period of time at 121% saturation but juveniles were more sensitive at lower gas levels.

Gas bubble disease signs for the cutthroat trout were similar to those described by Dawley et al. (1976) and Nebeker and Brett (1976) for other juvenile salmonids tested in similar systems. Tissue alterations included emphysemas on the fins, opercles, head, and jaws, and emboli in the bloodstream. Exophthalmia occurred in a small percentage of the fish exposed for longer periods of time. Fish held at lower concentrations exhibited more signs of sublethal gas bubble disease due to longer exposure time, while many of those held at 130% died before any external signs became evident.

Discussion

In comparing these two fish species it is apparent that there is a major difference in their sensitivity and response to air-supersaturated water. The 96-hour LC50 for speckled dace was 140% saturation, while that for juvenile cutthroat trout was 119% saturation. These differences in a field situation such as the Kootenai River below Libby Dam indicate that there is a much greater likelihood of damage to the cutthroat trout than to the speckled dace. The difference in threshold concentrations was also great, with mortality beginning at 113% saturation for juvenile cutthroat trout, and 119% for speckled dace. There were also obvious differences in the gas bubble disease signs exhibited by the two fish species. Emphysemas in the fin rays were very common for the cutthroat trout, and is a good sign to look for in the field

when supersaturation problems are suspected; this rarely occurred in the speckled dace. Exophthalmia was very common in the speckled dace but only occurred after many days exposure in just a small percentage of the cutthroat trout.

There are no data in the literature for speckled dace with which comparisons can be made; however, cutthroat trout sensitivity is similar to that of steelhead and sockeye salmon (*Oncorhynchus nerka*) (Nebeker and Brett 1976). Blahm et al. (1976) compared the time to death of cutthroat trout to that of eight other species at 130% and 120% N_2 saturation. At 130% N_2 saturation cutthroat trout appeared to be more tolerant than eulachon (*Thaleichthys pacificus*), steelhead trout, coho salmon (*Oncorhynchus kisutch*), or mountain whitefish (*Prosopium williamsoni*); less tolerant than rainbow trout (*Salmo gairdneri*), crappie (*Pomoxis* sp.), or largemouth bass (*Micropterus salmoides*); and equal in tolerance to chinook salmon (*Oncorhynchus tshawytscha*). Fifty percent of the cutthroat trout had died at 24 hours at 130% N_2 and at 119 hours at 120% N_2. May and Huston (1975) studied the effects of supersaturation on cutthroat below Libby Dam on the Kootenai River in Montana. They found that complete mortality occurred in 1.5 to 3.8 days when fish were held within 1 m of the surface at total gas levels of 131–139% saturation. When held in volition cages extending to 3 m depth, cutthroat trout suffered 55% mortality after 24 days. Fickeisen and Montgomery (1978) found that all cutthroat trout in their depth-study tank (132% saturation at surface) were dead after 24 hours at 128% saturation (calculated from depth below surface), and all were dead by 72 hours at 120% saturation. One fish survived the full 10 days at 116% saturation, giving fairly good correlation with the present study. The data from the present study indicate that if cutthroat trout and speckled dace were living in the same stream system and were subjected to air supersaturation the stress would exert significant selective pressure for survival favoring speckled dace over cutthroat trout.

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